In : Lee, Jeffrey A. and Zobeck, Ted M., 2002, Proceedings of ICAR5/GCTE-SEN Joint Conference, International Center for Arid and Semiarid Lands Studies, Texas Tech University, Lubbock, Texas, USA Publication 02-2 p.25

Wind-driven Rainsplash Erosion

G. Erpul * Faculty of Agriculture, Dept. Soil Sci., Ankara Univ., 06110 Diskapi - Ankara, Turkey.

L. D. Norton USDA - ARS National Soil Erosion Research Lab., 1196 SOIL Bldg., Purdue Univ., West Lafayette, IN, 47907-1196, USA.

D. Gabriels Department of Soil Management and Soil Care, Ghent University, Coupure Links 653, B 9000 Ghent, Belgium.

Introduction

The erosion process involves detachment of soil particles from a soil surface and transport of these particles from their first location. The main agents that loosen, break down, and carry the soil particles are wind and water.

Wind and water erosion processes have traditionally been separately studied, and independent models were developed to predict soil erosion by either wind or rain. In nature, erosive rainstorms are usually associated with high winds. Therefore, a quantification of wind and rain interactions and the effects of wind on detachment and transport processes provides a great opportunity for a given technology to improve the estimation of erosion.

Soil detachment and transport under wind-driven rain differs from that under windless rain (Lyles et al., 1969, 1974; Disrud and Krauss, 1971; Moeyersons, 1983; De Lima et al., 1992). Usually, if a raindrop falls at an angle, only the component of velocity normal to the soil surface gives rise to an impact pressure (Ellison, 1947; Springer, 1976; Gilley and Finkner, 1985). If we assume that the effect of the wind shear stress on the detachment is insignificant when compared to the effects of the impacting raindrops, the detachment rate at which soil particles are supplied into the air is a function of the normal component of raindrop impact velocity. Additionally, wind, as well as overland flow, is another possible factor capable of transporting the detached particles. Consequently, our approach to the rainsplash transport process under wind-driven rain is based on the concept that once lifted off by the raindrop impact, the soil particles entrained into the splash droplets travel some distance, which varies directly with the wind shear velocity. The raindrop impacts induce the process that wind would otherwise be incapable of transporting.

This paper presents experimental data obtained on the wind-driven rainsplash erosion and aims to provide a better basis for modeling the process.

Materials and Methods

The study was conducted in a wind tunnel rainfall simulator facility at Ghent University, Belgium (Gabriels et al., 1997). A continuous spraying system of downward-oriented nozzles was used at 1.5 bar operating pressure. A detailed description of the raindrop size distribution for the simulated rainfalls of the wind tunnel is given by Erpul et al. (1998, 2000).

Three loess derived agricultural soils, Kemmel1 sandy loam (57.6% sand, 31.1% silt, and 11.3% clay) and Kemmel2 loam (37.8% sand, 44.5% silt, and 17.7% clay) from the Kemmelbeek watershed (Heuvelland, West Flanders, Belgium) and Nukerke silt loam (32.1%

* Corresponding author: Faculty of Agriculture, Dept. Soil Science, Ankara University., 06110 Diskapi - Ankara, Turkey; phone: + 90 (312) 317 0550; + 90 (312) 317 8465; e-mail: erpul@agri.ankara.edu.tr

sand, 52.3% silt, and 15.6% clay) from the Maarkebeek watershed (Flemish Ardennes, East Flanders, Belgium) were used in this study. The soil samples were collected from the A_p horizon and air-dried prior to the experiment. Soil was sieved into three aggregate fractions: 1.00 - 2.75, 2.75 - 4.80, and 4.80 - 8.00 mm, and the weighing factors assigned to each fraction were 28, 32, and 40%, respectively to reconstitute the packing soil. A 5-kg soil sample was then packed loosely into a 55-cm-long and 20-cm-wide pan after the three fractions of aggregates were evenly mixed.

Rains driven by horizontal wind velocities of 6, 10, and 14 m s^{-1} were applied to the soil pan placed at both windward and leeward slopes of 7, 15, and 20%. There were three replicates for each soil and slope aspect.

Wind velocity profiles were measured up to 2-m-nozzle height with a vane type anemometer and associated recording equipment, and the wind velocity profiles above the soil pan were characterized by the following logarithmic equation:

$$u(z) = \left(\frac{u_*}{\kappa}\right)\ln\left(\frac{z}{z_o}\right) \text{ for } z > z_o \qquad [1]$$

where, u(z) is the wind velocity at height z, z_o is the roughness height, u_* is the wind shear velocity, and κ is von Karman's constant. The boundary layer was set at 0.30 m above the soil pan, subsequently, the reference shear velocities were derived from the logarithmic wind profiles, assuming a fixed roughness height of 0.0001 m for a bare and smoothed soil surface from the relation $z = ae^{bu}$, where, $a = z_o$ and $b = \kappa/u_*$.

The energy of simulated rainfalls was measured by a piezoelectric ceramic kinetic energy sensor (Sensit™, 2000). The kinetic energy sensor is a 5-cm ceramic disk and works on the piezoelectric effect of a ceramic disc, which produces electric charges proportional to the kinetic energy of impacting raindrops. The intensity of simulated rains (I) was directly measured with 5 small collectors on the inclined plane with respect to the prevailing wind direction.

In the present study, we assumed rainsplash detachment rate under inclined rain was related to the normal component of raindrop impact velocity. Accordingly, the fluxes of rain energy (KE) based on the normal velocity of raindrop impact was used as a rainfall parameter:

$$KE = \Xi_a \left(\frac{1}{2} m V_R^2\right) \phi^2 \qquad [2]$$

where, KE is in Wm^{-2} and m is the raindrop mass in kg. Ξ_a is the number of raindrops in # m^{-2} s^{-1} and calculated by $\Xi_a = I/\forall$, where, I is in ms^{-1}, and $\forall$ is the raindrop volume in m^3. ϕ is cosine of the angle of rain incidence between the wind vector and the plane of the surface and calculated by $\varphi = \cos(\alpha \mp \theta)$, where, α is the raindrop inclination from vertical (degree), and θ is the slope gradient (degree).

Rainsplash transport was evaluated by the amount of the splashed particles trapped at set distances on a 7-m uniform slope segment. Troughs were placed in the upslope and downslope directions, respectively, for windward and leeward slopes. The soil particles trapped in the collecting troughs were washed, oven-dried, and weighed. Mass distribution curves were then determined, from which rainsplash transport rates were calculated based on:

$$q_s = \frac{1}{At_r}\int m_i dx \qquad [3]$$

where, q_s is in g m^{-1} min^{-1}, A is the collecting trough area $(1.20\text{m} \times 0.14\text{m} = 0.168\text{m}^2)$, and t_r is the time (min) during which rainsplash process occurred. m_i is the mass of soil (g) splashed over the distance x_i (m).

Since soil particles left the surface with different initial lift-off speeds and angles, prediction of particle trajectories was considered as an average in this study. We used the first moment of the mass distribution curves (Van Heerden, 1967), which is the center of gravity of the curves, to approximate the mean rainsplash distance:

$$\sum_{i=1}^{n}(x_i - X)m_i = 0 \qquad [4]$$

and

$$X = \sum_{i=1}^{n} x_i m_i \Big/ \sum_{i=1}^{n} m_i \qquad [5]$$

where X is mean rainsplash distance (m).

Results and Discussion

Measured rainsplash rates varied in close relationship to the energy flux of rain and wind shear velocity. Similar results were obtained for all three soils. The statistical fit of the power law model for the combined data from three soils is:

$$q_s = 119.95 KE^{0.81} u_*^{2.09} \qquad [6]$$

The model of Eq. [6] performed equally well and provided similar R^2 values, which were ≥ 0.94 for three soils. The analysis of variance also showed that the model coefficients were significant at P = 0.0001 level of significance. The form of the model developed above features an integration of wind effects on the physical raindrop impact, and hence detachment, and on the transport process. In this experimental study, wind increased the raindrop resultant velocity and altered the angle of raindrop incidence, which resulted in a variable raindrop impact frequency and impact angle. Therefore, differential delivery rates occurred depending on the variations in raindrop trajectory and frequency with wind velocity and direction. More significantly, the wind had a greater effect on soil particle transport.

For the description of the average path of raindrop-induced splash droplet, a statistical analysis was conducted with non-linear regression model of:

$$X = C_1 (u_*^2/g) \qquad [7]$$

where X is expressed in unit of m, u_* in units of m s^{-1}, and g is the gravitational acceleration and in units of m s^{-2}. C_1 is a model parameter. Eq. [7] shows the fit of the data collected in this study, and for all data C_1 is equal to 32.7 ± 1.9. An important point here is that the average trajectory of raindrop-induced particle movement is approximately 3 times greater than the trajectory of a typical sand particle (White and Schulz, 1977). Longer particle trajectory might result from a change in the ejection velocity of droplets and lower density of soil aggregates. The greater lift-off speeds are probably caused by the raindrop impact than that by hitting sand grains. Therefore, raindrop-induced particles could attain greater heights and travel longer distances.

Conclusions

A wind-tunnel study under wind-driven rains was conducted to determine the combined effect of rain and wind on the rainsplash transport process. Transport by this process for the three soils studied was adequately described ($R^2 \geq 0.94$) using log-linear regression technique by Eq. [6] relating transport rate to the rain energy flux and wind shear velocity. Equation [6] reflects the combined effect of rain and wind on the process, and also illustrates the twin effect of wind: one is on the detachment by changing the raindrop impact parameters, and the other is on transport by carrying the detached and lifted soil particles. Therefore, a model of this form could provide the basis for modeling interrill rainsplash transport under wind-driven rains, a common phenomenon in erosion events.

Average trajectory of a raindrop-induced and wind-driven particle was also adequately predicted by 32.7 (u_*^2/g), and the travel distance is found three times greater in raindrop-induced process than the path of a typical saltating sand grain. We ascribed this to the greater lift-off speeds possibly caused by the raindrop impact and the lower densities of soil aggregates.

References

De Lima, J. L. M. P., Van Dijck, P. M. and Spaan, W. P., 1992. Splash-saltation transport under wind-driven rain. Soil Technol., 5: 151-166.

Disrud, L. A. and Krauss, R. K., 1971. Examining the process of soil detachment from clods exposed to wind-driven simulated rainfall. Trans. ASAE, 90-92.

Ellison, W. D., 1947 (7 parts). Soil erosion studies. Agric. Eng., 28: 145-146; 197-201; 245-248; 297-300; 349-351; 407-408; 447-450.

Erpul, G., D. Gabriels, and D. Janssens. 1998. Assessing the drop size distribution of simulated rainfall in a wind tunnel. Soil and Tillage Research, 45: 455-463.

Erpul, G., D. Gabriels, and D. Janssens. 2000. The effect of wind on size and energy of small simulated raindrops: a wind tunnel study. International Agrophysics, 14: 1-7.

Gabriels, D., W. Cornelis, I. Pollet, T. Van Coillie and M. Quessar. 1997. The I.C.E. wind tunnel for wind and water erosion studies. Soil Technology, 10: 1-8.

Gilley, J. E. and S. C. Finkner. 1985. Estimating soil detachment caused by raindrop impact. Transactions of the ASAE 28(1): 140-146.

Lyles, L., Dickerson, J. D. and Schmeidler, N. F., 1974. Soil detachment from clods by rainfall: Effects of wind, mulch cover, and initial soil moisture. Trans. ASAE, 17: 697-700.

Lyles, L., Disrud, L. A. and Woodruff, N. P. 1969. Effects of soil physical properties, rainfall characteristics, and wind velocity on clod disintegration by simulated rainfall. Soil Sci. Soc. Am. Proc., 33: 302-306.

Moeyersons, J., 1983. Measurements of splash-saltation fluxes under oblique rain. Catena suppl., 4: 19-31.

Sensit™, 2000. Model V04, Kinetic Energy of Rain Sensor. Sensit Company, Portland, ND 58274-9607.

Springer, G. S., 1976. Erosion by liquid impact. John Wiley and Sons, Inc., New York.

Van Heerden, W. M., 1967. An analysis of soil transportation by raindrop splash. Trans. ASAE, 10:166-169.

White, B. R. and Schulz, J. C., 1977. Magnus effect on saltation. Journal of Fluid Mechanics. 81: 497-512.